

WHAT IS CLAIMED IS:

1. A method for numerical analysis of a flow field
of incompressible viscous fluid, directly using V-CAD data,
5 comprising:

a dividing step (A) of dividing external data into a
plurality of cells (13) having boundaries orthogonal to
each other, the external data including boundary data of an
object which contacts incompressible viscous fluid;

10 a cell classifying step (B) of classifying the
divided cells into an internal cell (13a) positioned inside
or outside the object and a boundary cell (13b) including
the boundary data;

a cut point determining step (C) of determining cut
15 points in ridges of the boundary cell on the basis of the
boundary data;

a boundary face determining step (D) of determining a
polygon connecting the cut points to be cell internal data
for the boundary face; and

20 a analyzing step (E) of applying a cut cell finite
volume method combined with a VOF method to a boundary of a
flow field to analyze the flow field.

2. A method for numerical analysis of a flow field
25 of incompressible viscous fluid, according to claim 1, the
analyzing step (E) comprising:

applying a two-dimensional QUICK interpolation scheme to a convection term for space integral;

applying central difference having precision of a degree of a second order to a diffusion term;

5 combining the convection term and the diffusion term, and applying Adams-Bashforth method having precision of a degree of a second order to the combined convection term and diffusion term for time marching; and

applying an Euler implicit method having precision of
10 a degree of a first order to a pressure gradient term for time marching.

3. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 2,
15 wherein for a two-dimensional boundary cell, a governing equation in the finite volume method is expressed by a governing equation (7) of Formula 1,
[Formula 1]

$$\iint_{V_{i,j}} \frac{\partial \bar{u}}{\partial t} dV = - \iint_{V_{i,j}} \text{div}(\bar{u} \otimes \bar{u}) dV - \iint_{V_{i,j}} \text{div}(p\bar{I}) dV + \frac{1}{\text{Re}} \iint_{V_{i,j}} \text{div}(\text{grad}(\bar{u})) dV \quad (7)$$

20

4. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 3, wherein the convection term, the pressure gradient term and the diffusion term in the governing equation of the finite
25 volume method are expressed by the equations (8), (9) and

(10) of Formula 2, respectively,

[Formula 2]

convection term:

$$\begin{aligned}
 \iint_{V_{i,j}} \text{div}(\bar{u} \otimes \bar{u}) dV &= \oiint_{S_{i-5}} (\bar{u} \otimes \bar{u}) \cdot \bar{n} dS = \sum_{m=1-5} (\bar{u} \otimes \bar{u})_m \cdot \bar{n} \delta S_m \\
 &= [\Delta y (B_{i,j} u_{i,j}^{(x)} - B_{i-1,j} u_{i-1,j}^{(x)}) \\
 &\quad + \Delta x (A_{i,j} u_{i+1/2,j+1/2}^{(y)} - A_{i,j-1} u_{i-1/2,j-1/2}^{(y)})] \bar{i} \\
 &\quad + [\Delta y (B_{i,j} v_{i+1/2,j+1/2}^{(x)} - B_{i-1,j} v_{i-1/2,j-1/2}^{(x)}) \\
 &\quad + \Delta x (A_{i,j} v_{i,j+1/2}^{(y)} - A_{i,j-1} v_{i,j-1/2}^{(y)})] \bar{j} \quad | \text{only no-slip on wall}
 \end{aligned} \tag{8}$$

pressure gradient term:

$$\begin{aligned}
 \iint_{V_{i,j}} \text{div}(p \bar{I}) dV &= \oiint_{S_{i-5}} (p \bar{I}) \cdot \bar{n} dS = \sum_{m=1-5} p_m \bar{I} \cdot \bar{n} \delta S_m \\
 &= \Delta y [B_{i,j} p_{i+1/2,j} - B_{i-1,j} p_{i-1/2,j} - p_p (B_{i,j} - B_{i-1,j})] \bar{i} \\
 &\quad + \Delta x [A_{i,j} p_{i,j+1/2} - A_{i,j-1} p_{i,j-1/2} - p_p (A_{i,j} - A_{i,j-1})] \bar{j}
 \end{aligned} \tag{9}$$

diffusion term:

$$\begin{aligned}
 \iint_{V_{i,j}} \text{div}(\text{grad}(\bar{u})) dV &= \oiint_{S_{i-5}} \text{grad}(\bar{u}) \cdot \bar{n} dS = \sum_{m=1-5} \text{grad}(\bar{u})_m \cdot \bar{n} \delta S_m \\
 &= [\Delta y (B_{i,j} \text{grad}(u)_{i+1/2,j}^x - B_{i-1,j} \text{grad}(u)_{i-1/2,j}^x - (B_{i,j} - B_{i-1,j}) \text{grad}(u)_p^x) \\
 &\quad + \Delta x (A_{i,j} \text{grad}(u)_{i,j+1/2}^y - A_{i,j-1} \text{grad}(u)_{i,j-1/2}^y - (A_{i,j} - A_{i,j-1}) \text{grad}(u)_p^y)] \bar{i} \\
 &\quad + [\Delta y (B_{i,j} \text{grad}(v)_{i+1/2,j}^x - B_{i-1,j} \text{grad}(v)_{i-1/2,j}^x - (B_{i,j} - B_{i-1,j}) \text{grad}(v)_p^x) \\
 &\quad + \Delta x (A_{i,j} \text{grad}(v)_{i,j+1/2}^y - A_{i,j-1} \text{grad}(v)_{i,j-1/2}^y - (A_{i,j} - A_{i,j-1}) \text{grad}(v)_p^y)] \bar{j}
 \end{aligned} \tag{10}$$

- 5 5. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 3, wherein when a no-slip boundary condition is used for a solid boundary, integral is performed on the solid boundary with the convection term being zero, a value of a middle point P of a cut line segment being used as an average for the pressure gradient term and the diffusion term, and a
- 10

space integral is performed with areas fractions being applied to all of the terms.

6. A method for numerical analysis of a flow field
5 of incompressible viscous fluid, according to claim 3,
wherein the boundary cell having the parameter smaller than
a threshold value of $VOF=0.01$ is regarded as a complete
solid,

for the boundary cell having the parameter larger
10 than the threshold value, a definition point for the
parameter calculated in a cut cell is set at a center of
the boundary cell,

and a definition point for a parameter in a ridge is
set at a center of a cell ridge, and a parameter at a
15 middle point of a line segment 4 is calculated by a linear
interpolation.

7. A method for numerical analysis of a flow field
of incompressible viscous fluid, according to claim 3,
20 wherein a drag force (in a flow direction) and a lift force
(in a direction vertical to the flow) acting on the object
are expressed by equations (12) and (13) of Formula 3,

[Formula 3]

drag force:

$$\begin{aligned}
 F_x = F_D &= \iint_V \left(\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} \right) dx dy \\
 &= \iint_V \left(\frac{\partial \sigma_{xx}}{\partial x} \right) dx dy + \iint_V \left(\frac{\partial \sigma_{xy}}{\partial y} \right) dy dx = \oint_S \sigma_{xx} ds + \oint_S \sigma_{xy} ds \\
 &= \int_{y_1}^{y_2} (\sigma_{xx} |_{f_1(y)} - \sigma_{xx} |_{f_2(y)}) dy + \int_{x_1}^{x_2} (\sigma_{xy} |_{g_1(x)} - \sigma_{xy} |_{g_2(x)}) dx \Big|_{\text{only Cartesian}}
 \end{aligned} \tag{12}$$

lift force:

$$\begin{aligned}
 F_y = F_L &= \iint_V \left(\frac{\partial \sigma_{yx}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} \right) dx dy \\
 &= \iint_V \left(\frac{\partial \sigma_{yx}}{\partial x} \right) dx dy + \iint_V \left(\frac{\partial \sigma_{yy}}{\partial y} \right) dy dx = \oint_S \sigma_{yx} ds + \oint_S \sigma_{yy} ds \\
 &= \int_{y_1}^{y_2} (\sigma_{yx} |_{f_1(y)} - \sigma_{yx} |_{f_2(y)}) dy + \int_{x_1}^{x_2} (\sigma_{yy} |_{g_1(x)} - \sigma_{yy} |_{g_2(x)}) dx \Big|_{\text{only Cartesian}}
 \end{aligned} \tag{13}$$

8. A method for numerical analysis of a flow field
 5 of incompressible viscous fluid, according to claim 3,
 wherein in fluid-structure interaction analysis
 accompanying a moving boundary, a fluid system and a
 structure system are separately analyzed each predetermined
 time interval, and boundary conditions for the fluid system
 10 and the structure system are explicitly used.

9. A method for numerical analysis of a flow field
 of incompressible viscous fluid, according to claim 8,
 wherein in analysis on a forcibly vibrated circular
 15 cylinder, the circular cylinder is set as one-mass-point

and one-degree-of-freedom system such that the circular cylinder is a solid structure elastically supported and vibrating in a direction vertical to the flow,

and Y-direction displacement of a center of the circular cylinder is given by the equation (17), and a velocity boundary condition in the Y direction for a surface of the circular cylinder is given by the equation (18),

$$y = A \sin(2\pi f_c t) \quad \dots (17)$$

$$v_w = A 2\pi f_c \cos(2\pi f_c t) \quad \dots (18).$$

10. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 9, wherein movement velocity of the vibrating circular cylinder obtained by the equation (18) is changed to be given each calculation time step for the velocity boundary condition on the flow field.

11. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 8, wherein in analysis on self-induced vibration due to an vortex shedding from the circular cylinder, a vibration equation having a dimension is expressed by the equation (19) or (20), using one-mass-point and one-degree-of-freedom dumper/spring model,

$$m \frac{d^2 \tilde{y}}{dt^2} + c \frac{d \tilde{y}}{dt} + k \tilde{y} = \frac{1}{2} \rho U_o^2 D C_L \quad (19)$$

$$\frac{d^2 y}{dt^2} + (4\pi h f_o) \frac{dy}{dt} + (2\pi f_o)^2 y = \frac{8h}{Sc} C_L \quad (20)$$

12. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 11, wherein the movement velocity of the vibrating circular cylinder calculated by the equation (20) is changed to be given each calculation time step for the velocity boundary condition on the flow field.

13. A method for numerical analysis of a flow field of incompressible viscous fluid, according to claim 11, wherein initial displacement and initial velocity of the circular cylinder are set to be zero, the lift force is explicitly given by using a current value, and the vibration equation is integral by the Newmark's β method to obtain vibration displacement and vibration velocity of the circular cylinder.

14. A device for numerical analysis of a flow field of incompressible viscous fluid, directly using V-CAD data, comprising:

an input device (2) for inputting external data including boundary data of an object (1) that contacts incompressible viscous fluid;

an external storage device (3) for storing substantial data of shape data and physical property data integrated into each other, and a storage operational program for the substantial data;

5 an internal storage device (4) and central processing device (5) for executing the storage operational program; and

an output device (6) for outputting a result of the execution;

10 wherein the device divides the external data into a plurality of cells (13) having boundaries orthogonal to each other, classifies the divided cells into an internal cell (13a) positioned inside or outside the object and a boundary cell (13b) including the boundary data, determines
15 cut points in ridges of the boundary cell on the basis of the boundary data, determines a polygon connecting the cut points to be cell internal data for the boundary face, and applies a cut cell finite volume method combined with a VOF method to a boundary of a flow field to analyze the flow
20 field.

15. A program for numerical analysis of a flow field of incompressible viscous fluid, directly using V-CAD data, causing a computer to perform:

25 a dividing step (A) of dividing external data into a plurality of cells (13) having boundaries orthogonal to

each other, the external data including boundary data of an object which contacts incompressible viscous fluid;

5 a cell classifying step (B) of classifying the divided cells into an internal cell (13a) positioned inside or outside the object and a boundary cell (13b) including the boundary data;

a cut point determining step (C) of determining cut points in ridges of the boundary cell on the basis of the boundary data;

10 a boundary face determining step (D) of determining a polygon connecting the cut points to be cell internal data for the boundary face; and

a analyzing step (E) of applying a cut cell finite volume method combined with a VOF method to a boundary of a
15 flow field to analyze the flow field.